Performance of HgCdTe Infrared Detectors with 5-10 μm Cutoff Wavelengths at 20-50K Operating Temperatures

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NGST Requires Extensions of HgCdTe FPA Technology Developed for Many Very Different Applications

Applications

strategic defense
seekers
imaging cameras
remote sensing
spectroscopy
astronomy

Requirements

wavelength
operating temperature
background flux
pixel format, pitch
noise
integration time
frame rate

NGST Goals and Requirements

5-10 μm cutoff
temperature ≈ 30K
0.1 - 1000 photons/sec
- low defect density
- low dark current
- low noise
- high QE

2048x2048
visible response

4 Key Hybrid FPA Technologies

Molecular Beam Epitaxy HgCdTe double layer crystal growth

p-on-n double layer planar heterojunction photovoltaic detector array fabrication

CMOS readout integrated circuit design and fabrication

balanced composite structure hybrid assembly and packaging

For $\lambda_c \geq 5$ μm HgCdTe Has Potential for Higher Operating Temperature than InSb or Si:As

	InSb	Si:As	$Hg_{1-x}Cd_xTe$		
Cutoff Wavelength (μm)	5.5	>20	2.5	5-10	5-10
Operating Temperature	20-30K	<10K	78K	20-50K	20-50K
Substrate	InSb	Silicon	Al_2O_3	CdZnTe	silicon
Substrate Removal	yes	no	no	no	no
Pixel Yield	high	highest	high	lower	lowest
Readout Integrated Circuit	CMOS	Custom CMOS	CMOS	CMOS	CMOS
Readout/Detector Thermal Expansion Mismatch	Thinned InSb conforms	None	Thinned readout conforms	Thinned readout conforms	None

Rockwell is just beginning to produce and test FPAs with $\lambda_c \geq 5$ μm optimized for low background astronomy. Much more data is needed for tradeoff analysis involving λ_c, temperature, dark current, QE, pixel yield, uniformity, etc.

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Summary of Progress Toward NGST Goals

University of Rochester collaboration

– 1st program, begun in 1991, tested 5 μm cutoff HgCdTe detectors and arrays on both Al_20_3 and CdZnTe substrates. Pixel yields were not competitive with InSb.

– Ongoing programs have goals of 10 μm cutoff wavelength, 30K operating temperature, and dark currents < zodiacal background current of $\approx$ 1000 e-/sec.

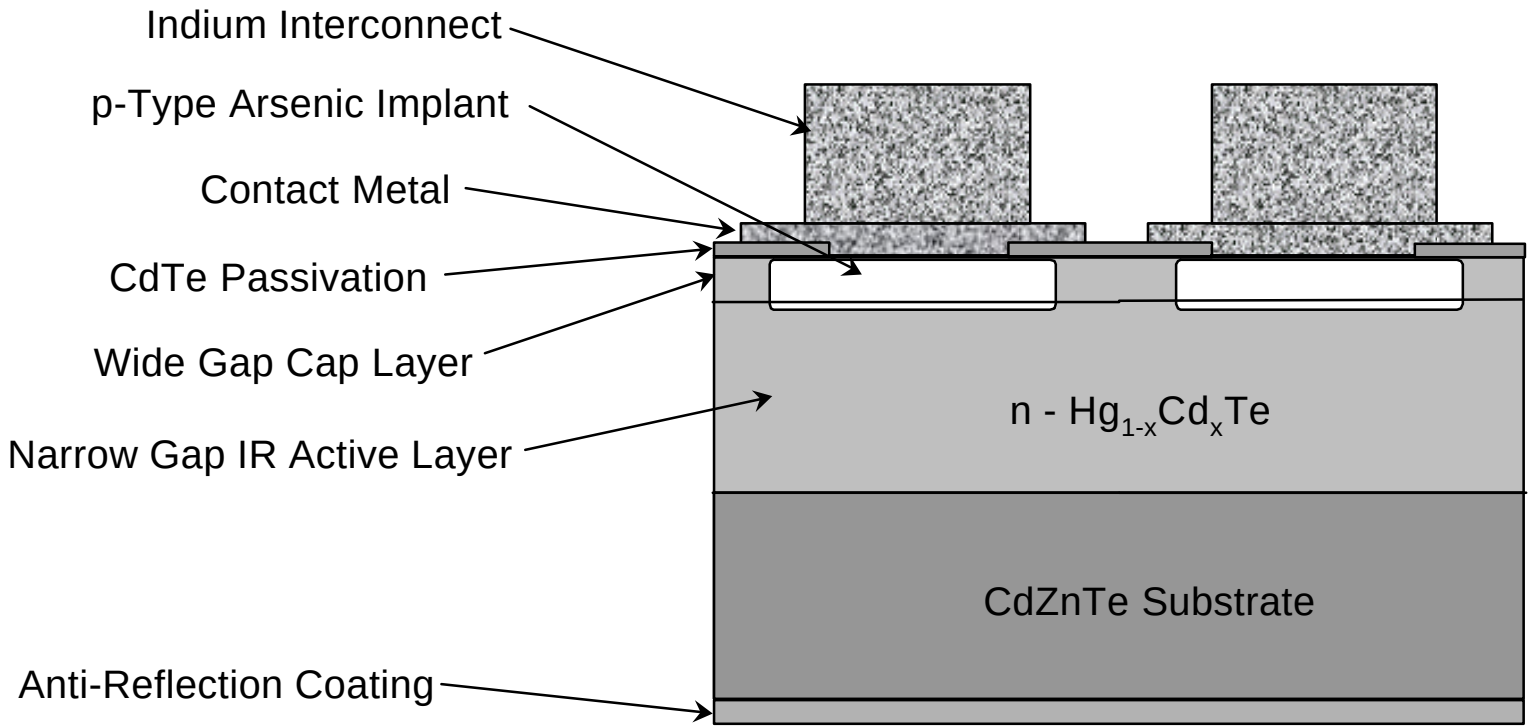
- Many λ_c = 10.6 μm test detectors have $I_{dark} < 10^4$ e-/sec @ 30K. One had < 1000 e-/sec
- Tunneling current model suggests potential 10x dark current reduction for modest detector base layer doping decrease
- First 256x256 FPAs fabricated specifically for this application are being assembled this week.

Summary of Progress Toward NGST Goals

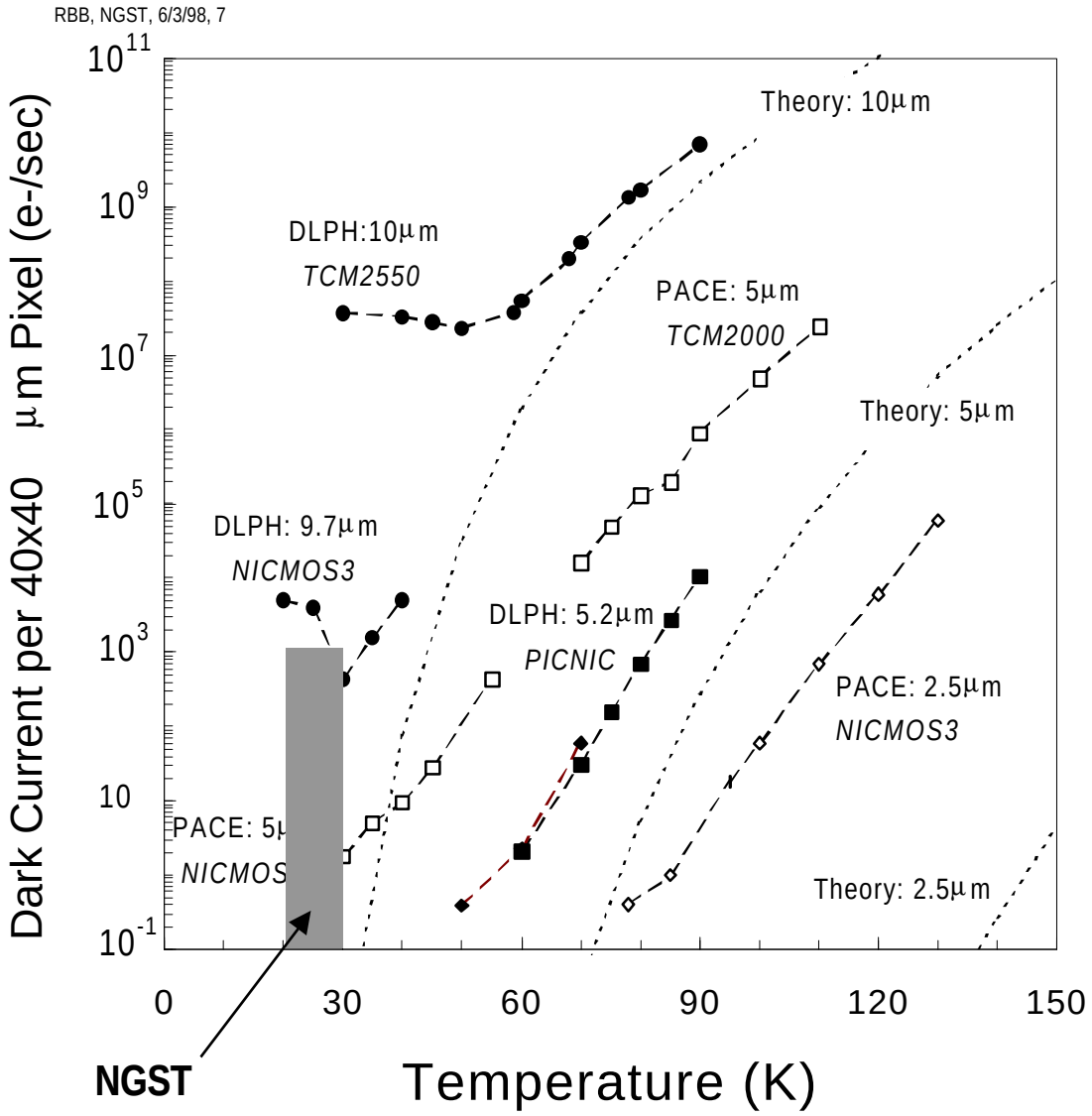
- **2048x2048 readout design includes multiple outputs to allow fast readout to handle higher photocurrents from 5 μm detectors**
- **For λ_c = 5.2 μm and CdZnTe detector substrate, mean I_{dark}=0.39 e-/sec @ 50K for 1 quadrant of PICNIC 256x256 FPA**
- **Large, reliable hybrid FPAs have been produced and tested to demonstrate the effectiveness of the balanced composite structure:**
  - **Silicon detector substrate:**
    - **1024x1024 pixels, 18 μm pitch**
    - **λ_c = 4.2 μm, QE = 0.58, 99.65% pixel yield, 5.4% response nonuniformity**
  - **CdZnTe detector substrate**
    - **640x480 pixels, 27 μm pitch**
    - **λ_c = 5.0μm, QE = 0.81, 98.2% pixel yield, 4.8% response nonuniformity**

Molecular Beam Epitaxy
Double Layer Planar Heterostructure (DLPH) Detectors

- **Precise control over layer doping, thickness, and composition variable x**
- **Low temperature crystal growth**
- **Lattice matched substrate reduces HgCdTe crystal defect density**
- **Wide band gap cap layer is easier to passivate.**



5.2 μm DLPH has 100x lower I_{dark} than 5 μm PACE



I_{dark} follows ideal diode T and λ_c dependence at high temperature with excess current from crystal defect and impurity states

5.2 μm median I_{dark}=0.39 @50K and 0.5V bias on 128x128 quadrant of PICNIC FPA

Nonuniform tunneling and shunt currents with weak temperature dependence become significant at the lowest temperatures

λ_c values in plot are @ 77K

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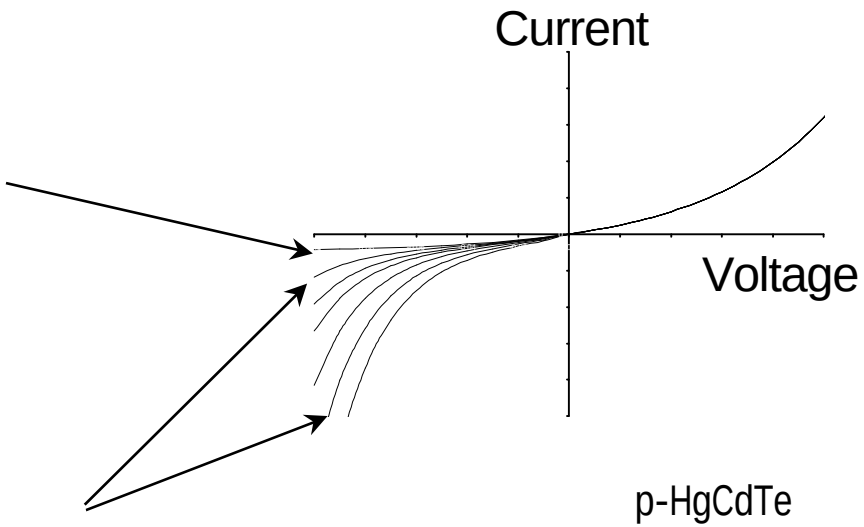
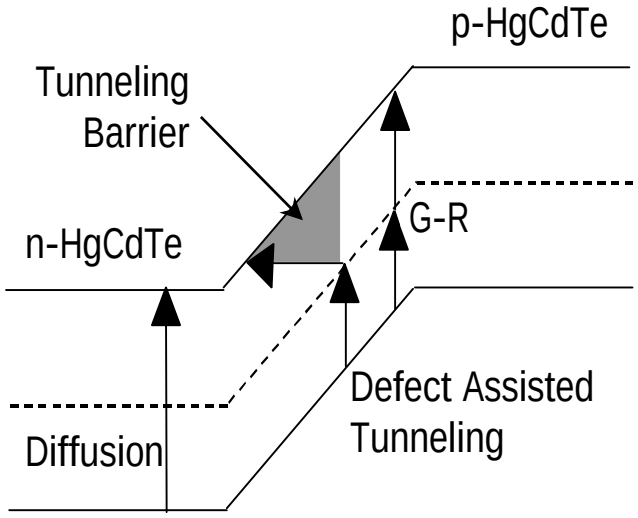
Dark Current Sources in HgCdTe Photovoltaic Detectors

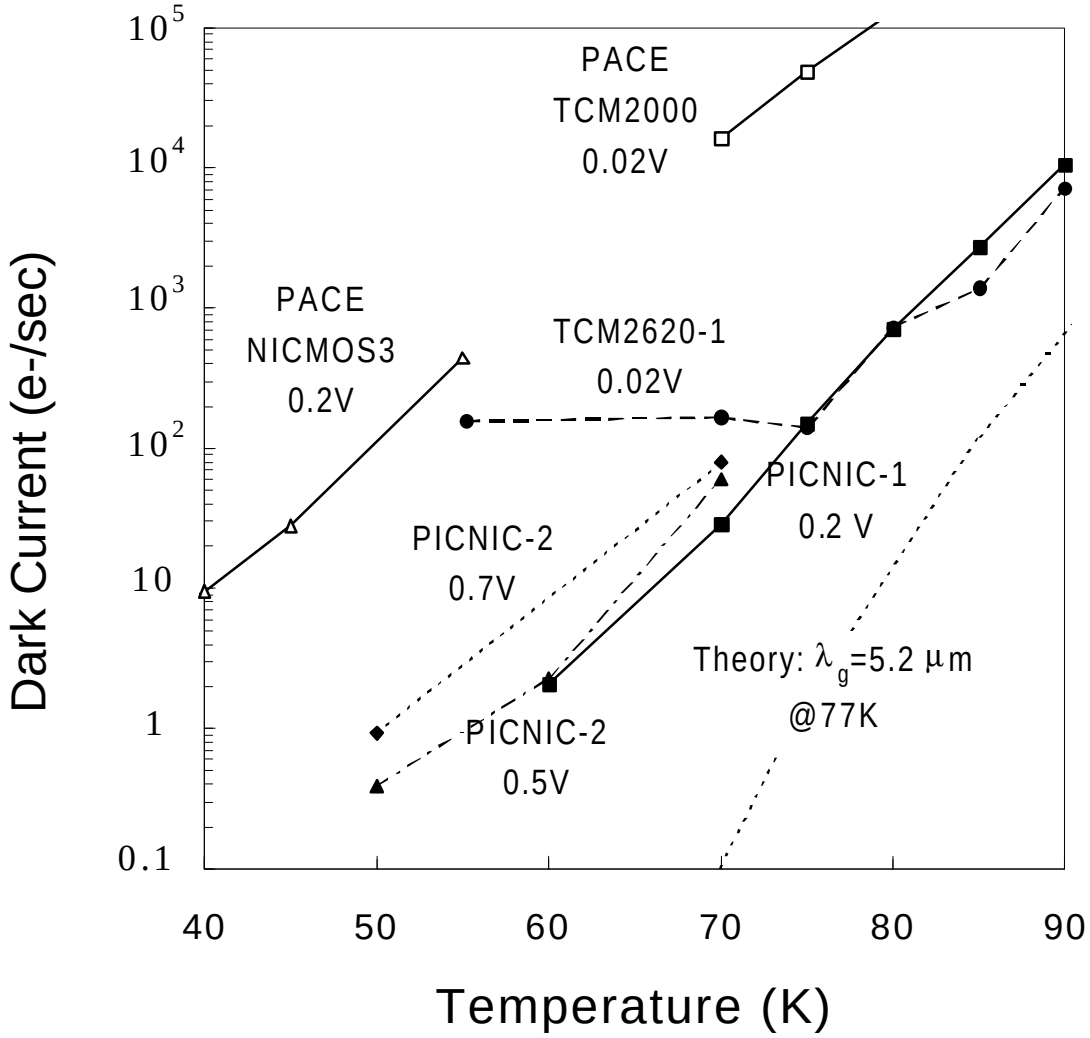
Thermally activated diffusion and G-R currents have strong T and λ_c dependence but weak bias dependence



Tunneling currents have strong bias and λ_c dependence but weak T dependence. Large pixel-to-pixel variations indicate that macro defects distributed randomly among pixels are the source.



FPA Median I_{dark} = 0.39 e-/sec at 50K for λ_c=5.2 μm



PICNIC readout has SFD input. Dark current increases with detector reverse bias voltage.

TCM2620 readout circuit has CTIA input and operates near zero bias. Infrared self-emission of readout provides most of the measured current below 75K.

p-on-n DLPH detector arrays on CdZnTe substrates have 100x lower I_{dark} than n-on-p PACE detector arrays fabricated on sapphire substrates.

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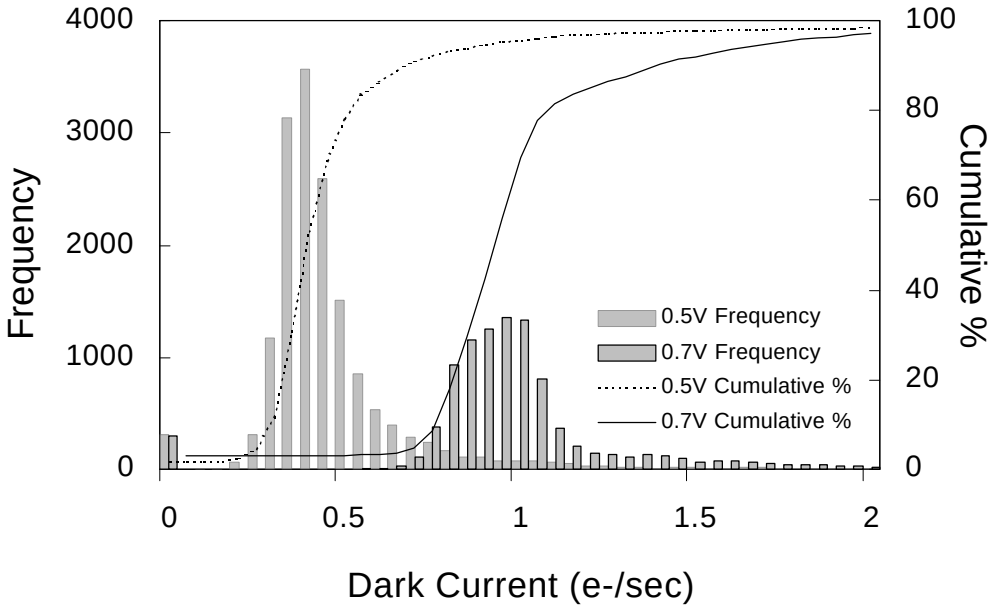
I_{dark} Distributions at 50K for FPA PICNIC-2 with λ_c=5.2 μm

Median I_{dark} increases from 0.39 e-/sec @ 0.5V bias to 0.95 e-/sec @ 0.7V.

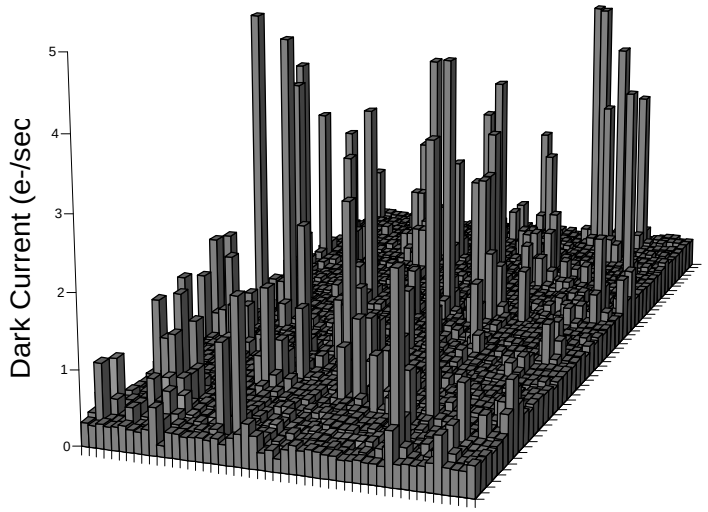
At 0.5V bias, 93.8% of pixels have I_{dark} < 1e-/sec.

High current pixels are distributed fairly randomly across array.

128x128 quadrant



50x50 subarray



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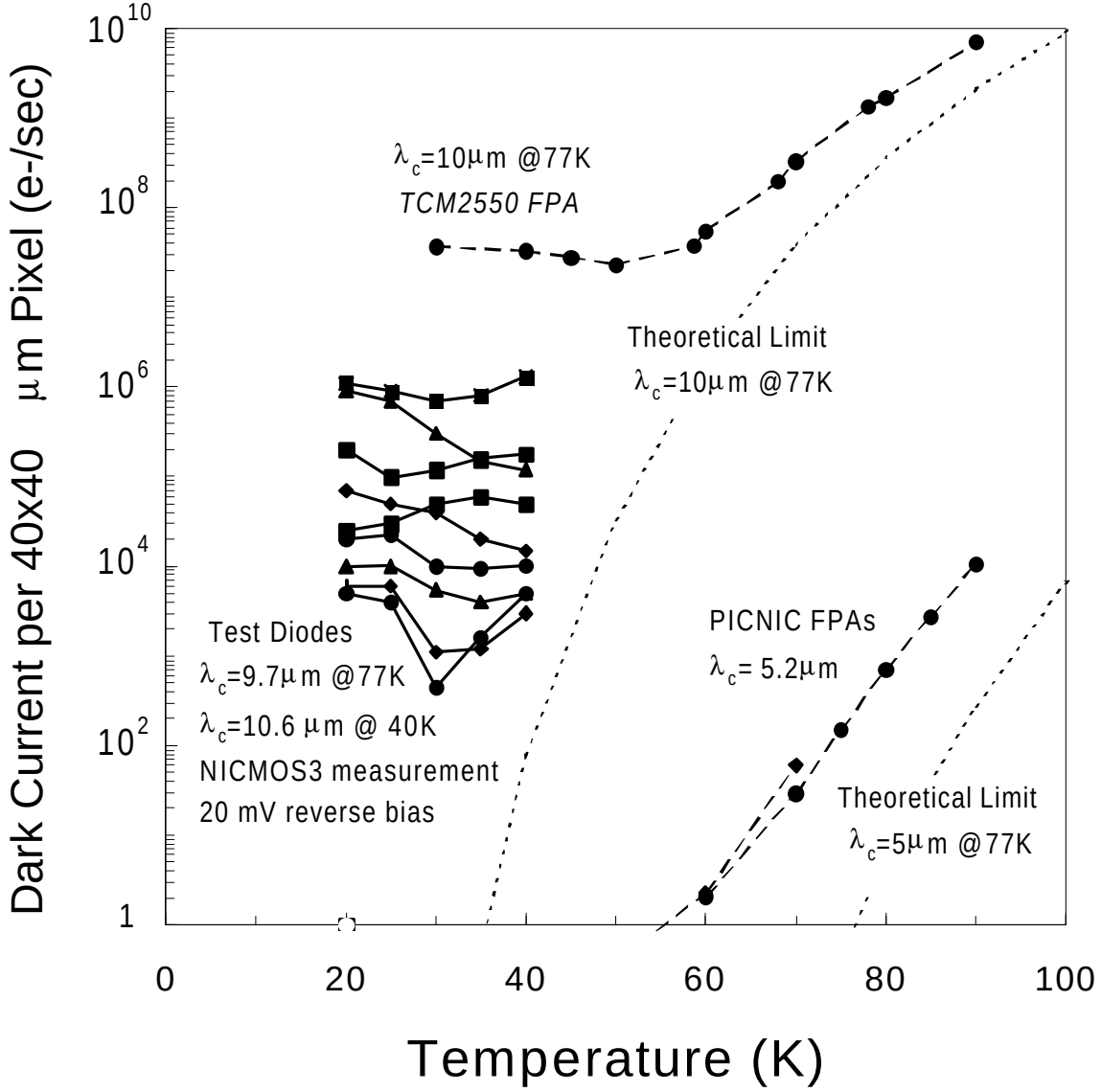
DLPH Test Detectors with λ_c=10.6μm Show Promise

RBB, NGST, 6/3/98, 11



Typical 256x256 TCM2550 FPAs from baseline process have median dark currents >2x10^7 e-/sec for T=30-70K.

Experimental test detectors, designed to minimize currents from crystal defects, have I_{dark} much closer to theoretical limits. They were wirebonded to NICMOS3 readout pixels for sensitive I-V measurements.

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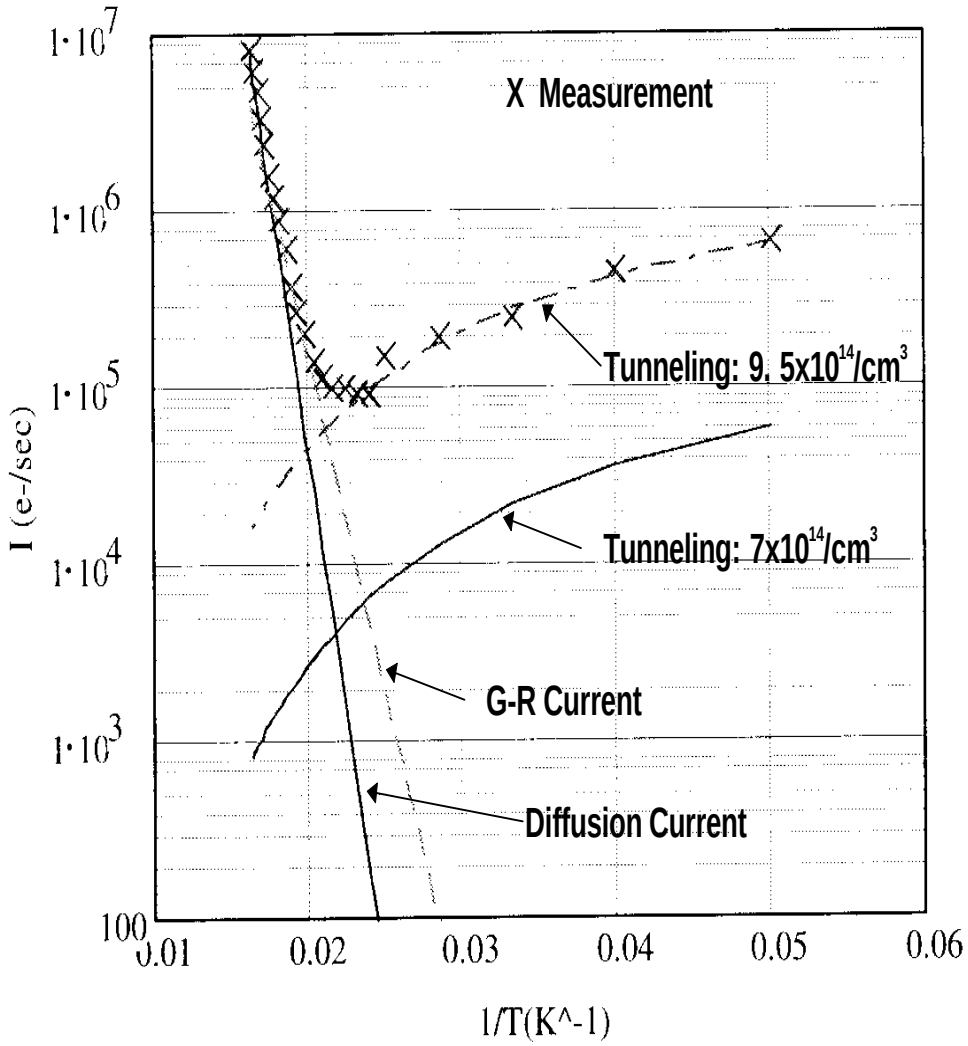
Tunneling Currents Decrease with DLPH Active Layer Donor Concentration N_d



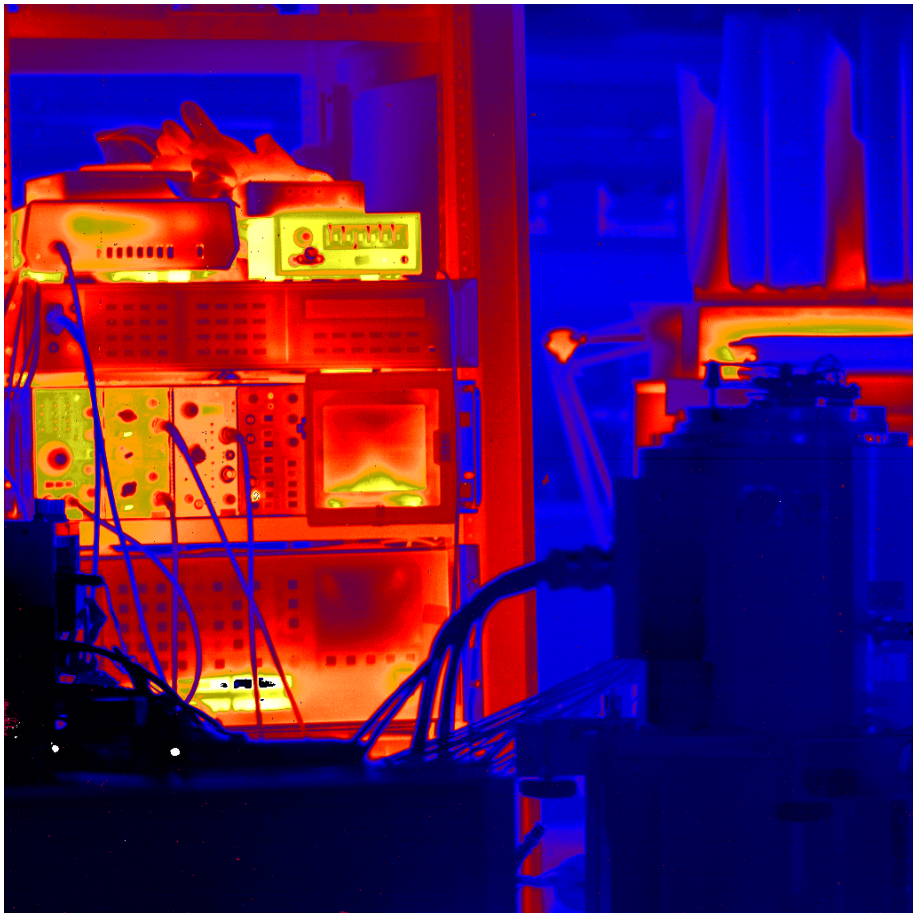
N_d=9.5x10^{14} for the λ_c=10.6 μm test detectors

Current vs T measured at 100mV reverse bias was fit to model including diffusion, G-R, and tunneling current.

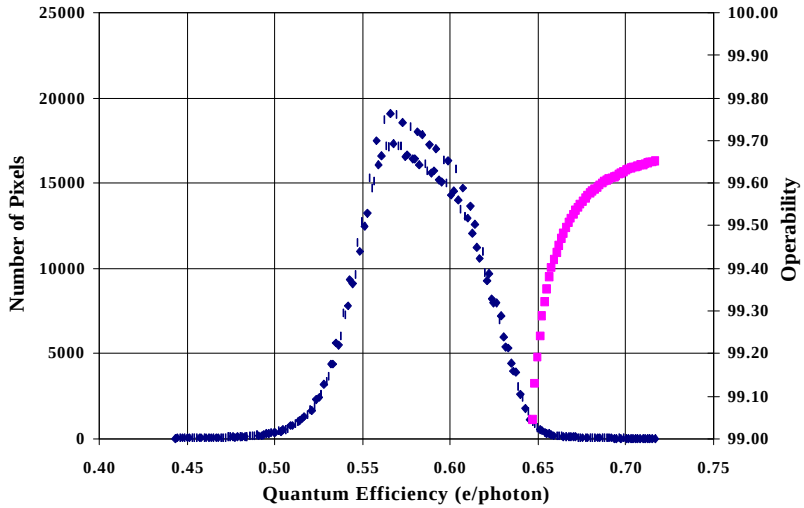
Model predicts 10x reduction in minimum dark current for N_d=7x10^{14}.

HgCdTe-on-Silicon 1024x1024 FPA Demonstrated

Laboratory Thermal Image, 77K, f/2, τ_{int} = 1 ms



- MBE Detector layer 2-540, λ_c=4.2 μm
- TCM8050 readout, 18 μm pitch
- Mean QE= 0.58
- Operability = 99.65% (pixels within 25% of mean QE)
- Std/Mean = 5.4%



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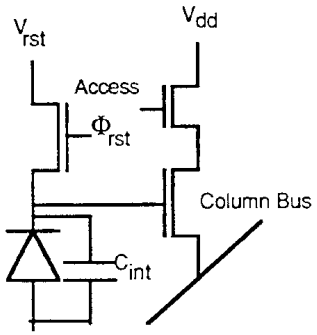
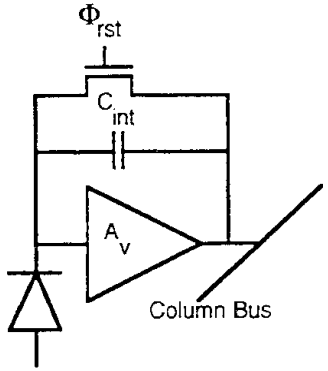
λ_c >> 5 μm Requires Different Mux Design



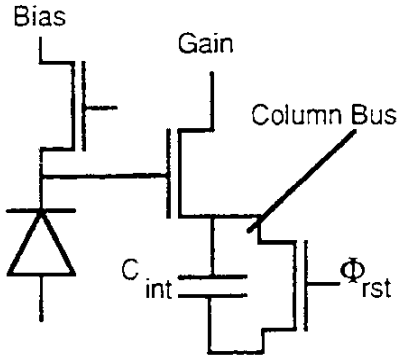
Source Follower per Detector (SFD) of NICMOS3 & HAWAII

- Signal integrates on reverse biased detector capacitance
- Dynamic range is limited by detector breakdown voltage
- Current flows in FETs only during reads not during integration



Capacitive Transimpedance Amplifier (CTIA)

- Mux feedback capacitor stores integrated detector current
- Amplifier maintains detector bias at nearly constant value that can be set close to zero.
- Infrared glow from FETs is proportional to amplifier current



Gate Modulation (GM)

- Can operate with high current gain to reduce read noise

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Summary and Conclusions

- **DLPH detectors and arrays fabricated on MBE grown HgCdTe crystal layers have demonstrated dark current performance useful for low background astronomical imaging at wavelengths between 5 and 10 μm.**
- **Operating temperatures for minimum dark current are above 30K so that passive cooling may be sufficient.**
- **More data is needed on detector arrays optimized for the NGST's very low background environment.**